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PERFORMANCE SUMMARY OF THE BALCOMB SOLAR HOME*

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ABSTRACT

The heating performance of the Balcomb passive solar home is re-evaluated based on detailed review of 85 channels of data taken during six weeks of 1980. This led to a re-analysis of 176 days of data taken over the winter of 1978-79. Auxiliary heat during this winter was 7.4 million Btu which compares with 66.0 million Btu total heat losses from the house plus 46.4 million Btu losses from the greenhouse. Auxiliary heat predicted using the solar load ratio method is 8.1 million Btu. Solar savings are estimated as 57 million Btu. Good thermal comfort conditions are documented. Energy flows are tabulated for each month. Conclusions regarding detailed heat flow and storage in the house are presented.

1. INTRODUCTION

The Balcomb solar home is located in Santa Fe, New Mexico at an elevation of 7200 feet. Winter conditions of 6000 heating degree days are characterized by long periods of sunny cold weather interrupted by cyclonic storms which bring cloudiness and appreciable snowfall. The house is primarily a passive design of the attached sunspace type and was designed and built by Susan and Wayne Nichols in 1976. Floor plans and a section are shown in Fig. 1. The total living area of 1950 sq ft is divided between an upper and lower floor both of which abut a 350 sq ft, two-story sunspace on the south. The house is well insulated with R25 (frame) exterior walls, R25 ceiling, double glazing, and a measured total infiltration leakage area of 0.97 sq ft, resulting in an overall measured loss coefficient of 10690 Btu/DD for the house and 5850 Btu/DD for the greenhouse.

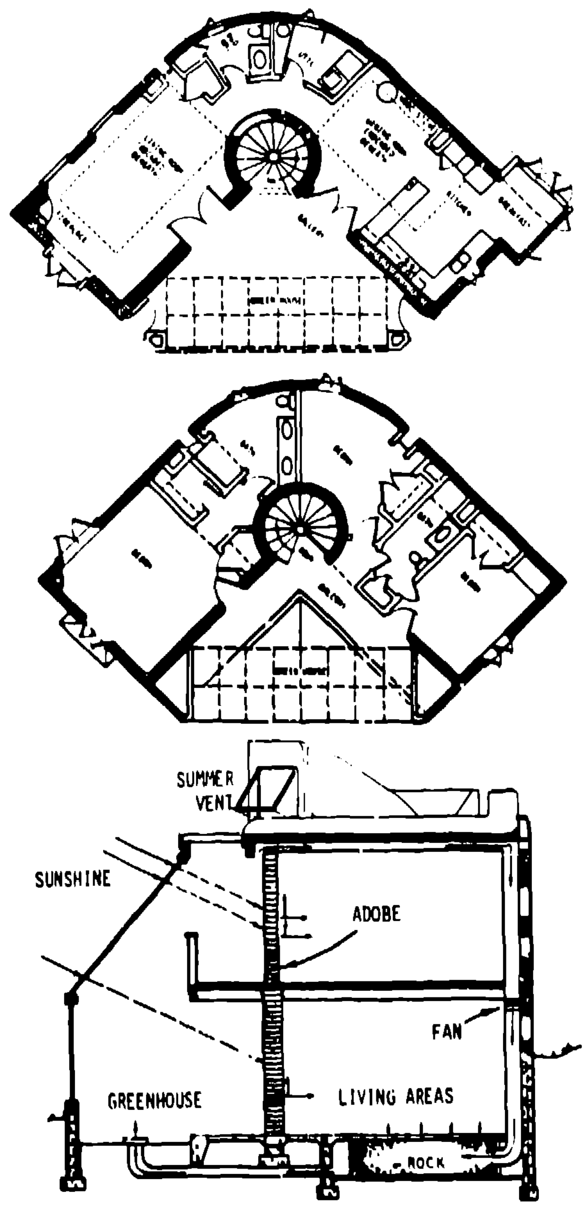

Fig. 1. Plans and SW-NE Section

Solar glazing on the greenhouse is 24 fixed, double glass sealed units totaling 273 sq ft at a 50° tilt and 136 sq ft vertical, both oriented 11° west of true south. Additional house glazing is 175 sq ft

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distributed approximately uniformly between SE, NE, NW and SW orientations. Heat storing mass is primarily in an uninsulated adobe wall which separates the greenhouse from the house, in two rock beds underneath the dining room and living room floors (actively charged by two fans which draw air from the greenhouse), in the plaster walls and wood ceilings of the house, and in the greenhouse floor.

A more complete description of the house is given in Refs. 1 and 2. A detailed Los Alamos report will be published describing the data, the analysis methods and the basis for the conclusions.

2. PREVIOUS EVALUATIONS

A major evaluation of the house for the period November 1, 1978 - April 24, 1979 was reported in Ref. 3. As a result of uncertainties which developed during this data analysis, much more detailed information was obtained during a six-week interval in the spring of 1980. Some results of the evaluation of this later data have been reported in Refs. 4 and 5.

3. DATA ANALYSIS METHODS

Hourly solar radiation measurements taken in a horizontal plane were separated into direct and diffuse components using the Boes' correlation[6] and then reassembled into solar radiation incident on each of the six glazing planes in the house. Glass transmittance was calculated using the Fresnel relationships and a typical extinction coefficient. Ground reflection was taken as 0.3 without snow and 0.7 with snow cover. An overall heat loss coefficient for the house was determined during a 16-day period in December 1978 based on the total electrical plus solar energy and the integrated degree hours for the house and greenhouse. The measured heat loss coefficient is 3% lower than the calculated value.

Daily energy flows were calculated for the following elements:

- Heat flow through the adobe wall which separates the house from the greenhouse was calculated hourly using a dynamic method described in Ref. 7 based on temperature measurements made at the inner and outer wall surface at three locations in the upper and lower walls.

- Convection through the doorways which separate the house from the greenhouse was determined hourly using a correlation validated by Weber and Kearney.[8] These values were calculated separately for the lower floor, the center bedroom upstairs, and the end bedrooms upstairs.

- Heat storage in the plaster walls and also in the wood roof beams and furniture of the house was estimated hourly based on air temperatures measured downstairs, in the center bedroom, and the end bedrooms. This analysis was done with a simple dynamic model which has been validated based on the detailed data taken in 1980.

- Heat required for the evaporation of water from plants and other sources of water within the house was estimated. This evaporation rate has been found to correlate well with the average greenhouse temperature and averages approximately 55 lb of water per day corresponding to an energy requirement of 57000 Btu per day.[4]

- Heat transported by the fans from the greenhouse to the rock beds, heat flow up through the floor slabs covering the rock beds into the dining room and living room, and heat flow into the ground underneath the rock beds were calculated using a pair of coupled two-dimensional models, one for the rock beds and another for the heat flow into the ground, around and through the perimeter insulation and up through the north berm. These models have been partially validated by comparison with both the 1978-79 and the 1980 data.

- Heat generated by a small wood-burning stove was estimated based on the hourly average flue gas temperatures using an empirical correlation determined during a controlled burn.

- Heat flow from the water heater to the house was estimated as 11780 Btu/day plus 25% of the electrical energy into the water heater. (During most of the analysis period the solar water heater was shut down for modifications.) People heat is estimated as 11000 Btu/day.

Two additional major heat flows occur occasionally which could not be directly estimated: 1) heat from a fireplace in the living room; and, 2) heat vented from the house by deliberate opening of doors and windows primarily during the months of November, March, and April. Since all of the other energy flows in the house can be reasonably well estimated, these unknown energies can be inferred from the residual energy imbalance of the house. The procedure used was to compute a running integral of this imbalance and attribute any excesses over 150000 Btu to either the fireplace (if the unbalance is negative) or to venting (if the unbalance is positive). The only validation of this approach is to note that the occurrences of this prediction coincide quite reasonably with times when both fireplace burning and venting were known to occur and that the total fireplace energy is a reasonable value based on the quantity of wood burned.

4. RESULTS

4.1 Energy Balance

Although the overall energy performance of the house is virtually the same as reported in Ref. 3, some significant differences were found in the internal energy flows, especially in the rock bed. It was also possible to better resolve various heat flow and storage terms. Monthly and annual energy flows are given in Table I and a few are summarized in Fig. 2.

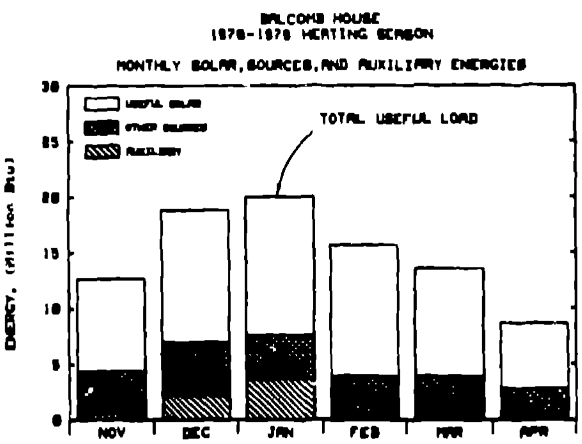


Fig. 2. Monthly Energies

In order to estimate energy savings the concept of a "useful load" was developed. The "useful load" is computed based on the degree hours computed between the measured house or greenhouse temperature and the outside temperature, but degree hours above an arbitrary fixed reference temperature are discarded. Thus one does not count as useful load any energy required to keep the space above the fixed reference level, which was set to 70 F for the house and 45 F for the greenhouse.

The "heating requirement" for the house is the useful load minus the internal energy generation by lights, people, water heater, and appliances. "Solar savings" is the heating requirement minus the auxiliary heat and totals 57 million Btu for the year or 89% of the heating requirement.

4.2 Thermal Comfort

Plots of the hours of occurrence in each one-degree temperature band are given in Fig. 3 for the dining room and greenhouse. The effect of mass wall buffering is very apparent in the dining room which has a small daily temperature swing of only 5 to 6 F. By contrast the uncontrolled greenhouse space has large temperature swings (30 F typical) clearly showing the two-zone nature of the house.

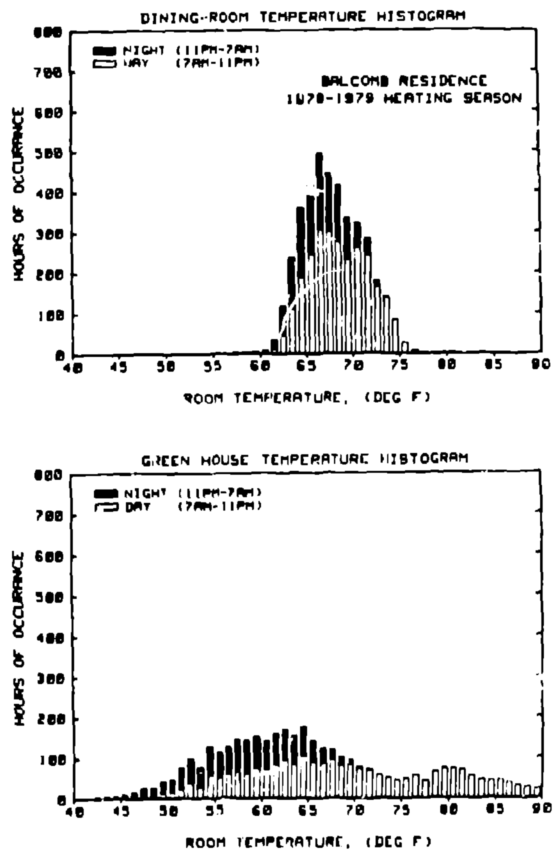


Fig. 3. Room Temperatures

6. CONCLUSIONS

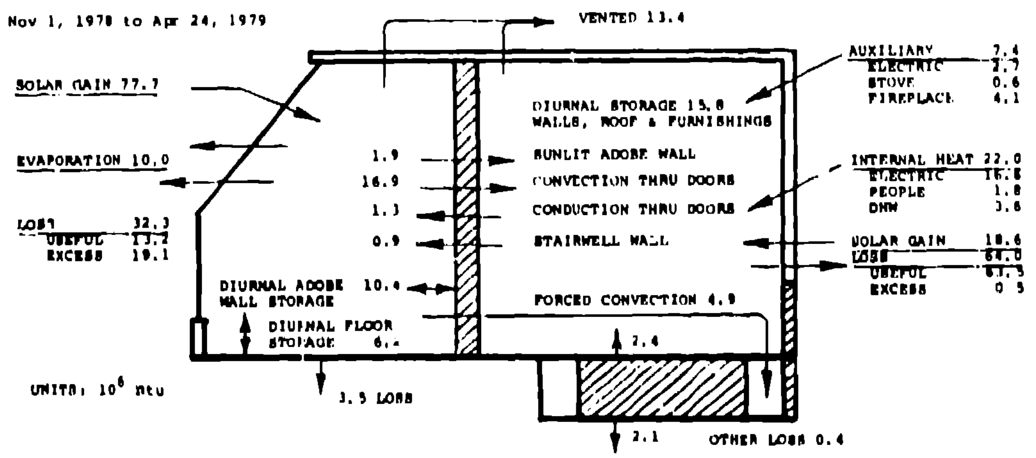
- The overall performance of the house has been extraordinary. It has provided good comfort conditions in a cold climate with very small requirements for auxiliary heat. Operation is simple and reliable.

- The greenhouse is an efficient solar collector. Approximately 31% of the solar radiation transmitted into the greenhouse is subsequently transferred to the house. In addition the greenhouse is adequately heated, maintaining conditions well above freezing, without auxiliary heat. A critical design feature which leads to greenhouse effectiveness is the ability to thermally isolate the house from the greenhouse by closing doors.

- The predominant mode of heat transfer between the greenhouse and the house is by convection through doorways which are opened during the daytime. The fact that the greenhouse serves as a major traffic area is important to the effectiveness of this control mechanism. Typical convection through a doorway is 50000 Btu on a sunny day for the upstairs bedrooms and 23000 Btu for the downstairs; this difference is due to the slightly-colder room temperatures

TABLE I

KBtu for Balcomb House, 1978-79	NOV	DEC	JAN	FEB	MAR	APR	YEAR
Solar Gains	13790	15416	15716	19800	18265	13224	96217
House	2360	2490	3114	3941	3593	3059	18559
Greenhouse	11430	12926	12604	15859	14672	10165	77658
Heat Losses	16628	22482	22827	20043	18407	11996	112394
House	9589	13916	14625	11632	10307	6483	66555
Greenhouse	4697	6428	6533	5968	5364	3315	32307
Evaporation	1772	1564	1159	1810	2082	1676	10066
Greenhouse to Ground	570	574	510	633	654	522	3466
Useful Load	12652	10799	19987	15662	13548	8652	89309
House	9506	13914	14625	11589	10104	6300	66041
Greenhouse	3146	4885	5362	4073	3444	2352	23268
Vented Energy	1503	0	491	3675	3752	3995	13415
Auxiliaries	563	2379	3734	524	230	27	7457
Baseboard Electric	262	894	1193	222	119	27	2718
Stove	0	302	273	0	0	0	576
Fireplace	301	1183	2268	302	111	0	4163
Internal Gains	3779	4685	3865	3392	3663	2740	22133
DHW Retained	752	820	729	593	442	275	3614
People	324	334	334	302	334	259	1890
Other Electric	2703	3531	2802	2497	2887	2206	16629
Greenhouse to House	3444	4356	2596	5069	3237	3075	21785
Convection thru Open Doorways	2513	3709	2397	3550	2504	2251	16932
Conduction through Doors	-177	-287	-347	-187	-187	-111	-1298
Adobe Wall	405	424	350	553	210	211	2155
Stairwell wall	-112	-240	-414	-27	-83	-38	-911
Forced Convection to Rockbed	809	750	610	1180	793	762	4907
Rockbed	809	750	610	1180	793	762	4907
Upward through Floor	491	366	365	479	375	297	2375
Downward into Ground	311	330	271	492	389	363	2159
Other Rockbed Losses or Gains	7	54	-26	209	29	102	373
Heating Required	8873	14114	16122	12270	9885	5912	67176
Solar Savings	8310	11735	12388	11746	9655	5885	59719
SOLAR LOAD RATIO PREDICTION							
Auxiliary Heat Predicted	417	2320	3927	953	416	59	8092
Auxiliary Heat Observed	563	2379	3734	524	230	27	7457
AVERAGE TEMPERATURES (F)							
Dining Room	67.7	67.4	65.7	68.3	69.0	69.4	67.9
West Bedroom	68.5	65.7	63.0	70.1	71.7	70.2	68.2
Center Bedroom	65.1	61.7	59.6	67.2	69.0	70.0	65.4
Greenhouse	64.8	61.5	57.6	66.4	67.1	68.1	64.2
Outside Ambient	38.1	26.2	22.2	31.4	39.6	44.9	33.6
Rockbed	74.5	72.4	69.9	75.5	73.8	74.4	73.4
Floor Surface above Rockbed	69.2	68.6	66.7	70.0	70.2	70.5	69.2



and higher greenhouse temperatures upstairs. The typical driving ΔT upstairs is 15 F. Much of this heat goes to satisfying daytime loads but about 40% is stored in plaster walls, wood-beamed ceiling, and house furnishings.

- The primary importance of the massive adobe wall between the house and the greenhouse is for direct-gain storage in the greenhouse. Most of the heat absorbed by the wall is released back to the greenhouse at night and is essential to maintaining reasonable temperature conditions in the greenhouse. The amount of heat transmitted through the wall to the house is 1.9 million Btu for the year. This effect is larger upstairs due to less shading of the wall, slightly lower room temperatures, and a thinner wall (10 inches vs 14 inches downstairs).

- Heat storage in the plaster walls, wood-beamed ceiling, and furnishings of the house is significant. Carryover heat from one day to the next is observed on 89 of the 176 days of the analysis period, averaging 49200 Btu per day. Diurnal heat storage (heat stored and released during the same day) occurs nearly every day and averages 89800 Btu per day.

- The effect of water evaporation in the greenhouse is significant in improving the living quality by increasing the humidity into the 20% to 50% comfort range but this is at the expense of about 57000 Btu per day of energy.

- The rock bed definitely appears to have a positive effect on the heating and especially the comfort characteristics of the house although less than originally estimated. About 53% of the heat deposited in the rock bed is conducted up through the floor slab into the living area. The remaining 47% is conducted into the ground underneath the rock bed (the perimeter of the rock bed is insulated with 2 inches of foam but it is not insulated underneath). The average floor surface temperature above the rock bed is 69.2 F which compares with 60 F measured on the floor well away from the rock bed. The beneficial effect of this increase in floor temperature allows a decrease in air temperature of the room of about 2°F in order to maintain equivalent comfort conditions. It is also important to note that heat would be lost from the floor even if the rock beds were not present. The net benefit of the rock bed to the house is estimated as 30000 Btu per day or 5.3 million Btu per year combining the direct and two indirect effects. Another benefit of the system is the 10 to 15 degree reduction in greenhouse temperatures observed when the fan is operated. As discussed in Ref. 5, reverse thermosiphon from the rock bed to the greenhouse can significantly impair the effective performance of the system; backdraft dampers prevent this degradation.

- Summer weather in Santa Fe is mild with large diurnal swings. Maximum house temperatures are 82 F upstairs and 78 F downstairs without air conditioning. Overheating which might be caused by the greenhouse is prevented by sun control, good ventilation, and night-vent cooling of the large house mass. The greenhouse roof and second-floor balcony effectively shade the adobe wall. Cross ventilation and stack ventilation remove excess heat.

7. PREDICTION USING SLR METHOD

The monthly solar load ratio (SLR) method[9] has been used to estimate auxiliary heat based on the actual observed solar radiation and net heating requirements. The house was treated as a mixture of semi-enclosed sunspace (to account for the greenhouse) and direct gain (to account for the SE, SW, NW, and NE house windows). The predicted annual auxiliary heat required is 8.1 million Btu, in excellent agreement with the observed 7.4 million Btu. Monthly values are given in Table I.

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